Environ Geochem Health (2009) 31:353–363
DOI 10.1007/s10653-008-9175-8

ORIGINAL PAPER

Geographic patterns of non-carpeted floor dust loading in Syracuse, New York (USA) homes

D. L. Johnson · A. Hunt · D. A. Griffith · J. M. Hager · J. Brooks · H. StellaLevinsohn · A. Lanciki · R. Lucci · D. Prokhorova · S. L. Blount

Received: 8 February 2007 / Accepted: 2 April 2008 / Published online: 3 May 2008

Abstract Residential floor dust loading was measured on the smooth floor surface of 488 houses in Syracuse, New York, during the summers of 2003 and 2004. Using U.S. Environmental Protection Agency (EPA) wipe methods, pre-weighed Ghost Wipes, Lead Wipes, or Whatman Filters were employed to collect duplicate samples from (predominantly) kitchens. The collection efficiency of the various media was determined from multiple wipe tests and side-by-side comparisons. The results were normalized and aggregated at the census tract level to determine whether spatial patterns of dust loading could be observed. Loading was found to be log-normally distributed, with a geometric mean value of 0.311 g m^{-2} (29 mg of dust per square foot of floor); 95% of the observations fell in the range of 0.042–2.330 g m^{-2} (4–216 mg $foot^{-2}$). The sampling for floor dust loading shows some bias for day of the week in which visits to the residential properties were made. After a first-order correction for this effect, results were aggregated by census tract and mapped in a geographic information system (GIS); strong spatial patterns can be identified in an inverse distance weighted mapping. The geographic patterns exhibit a strong correlation with socio-economic/demographic covariates extracted from the 2000 census summaries. Dust mass on the floors is positively correlated with renter-occupied properties and family size; it is negatively correlated with measures of household income.

Keywords Demographic correlates · Dust loading · House dust · Spatial patterns · Wipe samples

D. L. Johnson (✉) · J. M. Hager · J. Brooks · H. StellaLevinsohn · A. Lanciki · R. Lucci · D. Prokhorova · S. L. Blount
Department of Chemistry, State University of New York/Environmental Science and Forestry (SUNY/ESF), 1 Forestry Drive, Syracuse, NY 13210, USA
e-mail: dljohnson@esf.edu

A. Hunt
Upstate New York Specialist Environmental Consulting (UNYSPEC), Baldwinsville, NY 13027, USA

D. A. Griffith
School of Economic, Political and Policy Sciences, University of Texas at Dallas, Richardson, TX 75083, USA

Introduction

Both the health effects and the environmental quality determinants of indoor dust have received substantial attention in recent years (Kildeso et al. 1999; Pesonen-Leinonen et al. 2004). Since people in the USA spend most of their time indoors (Klepeis et al. 2001), two-thirds of it in residential settings, human health risk assessments focusing on toxic materials need to consider the connection between the outdoor soil reservoirs and the indoor sites of exposure. Contaminants of urban and industrial environments, such as heavy metals, polycyclic aromatic hydrocarbons (PAHs), and pesticides, are routinely identified in house dusts (Paustenbach et al. 1997; Butte and Heinzow 2002; Lemley et al. 2002; Lioy et al. 2002; Lambert and Lane 2004; Lewis et al. 1994). The adverse health impact of soil and dust contaminants on sensitive populations has been amply demonstrated. For example, many epidemiologic investigations have illustrated the association between soil Lead (Pb) levels, indoor dust Pb levels, and pediatric blood Pb levels (Lanphear et al. 1998). While opportunities for advancing our understanding of their transport dynamics may be realized through the construction of quantitative models (Schneider et al. 1999), few detailed studies have been carried out that describe the quantitative distribution of household dust itself. Spatial patterns of floor dust loading may be important considerations in the development of contaminant exposure assessments.

As part of a larger geography-based urban metal exposure assessment, dust wipe sampling was carried out in 488 homes within the (68.5 km^2) city limits of Syracuse, New York, USA. A description of the sampling program, along with some of its initial results, can be found in Johnson et al. (2005). Wipe sampling methods were utilized because an issue of local concern was dust lead loading and its possible relationship to children blood lead levels (Lanphear et al. 1998; Succop et al. 1998); those results are reported in detail elsewhere. Dust loading was also measured, and the present work reports the complete geographic survey of floor wipe sampling for gravimetric dust mass across the city. It describes the field use and comparison of three pre-weighed wipe media and details the gravimetric mass detection limits and collection efficiency differences between the various media. Sampling locations in this informed consent study were visited without prior arrangement and thus represent an approximately random distribution across the aggregate of time periods since the last cleaning of floor surfaces. We view the results as a quasi-synoptic picture of summer time floor dust loadings within this medium-sized post-industrial northeastern USA urban center.

Experimental

Study area

The city of Syracuse is located south of Lake Ontario in central upstate New York along historic transportation corridors that are now the routes of Interstate Highways 81 and 90. From the mid-19th to the mid-20th century, railroad maintenance shops and major manufacturing facilities for glass, china, agricultural equipment, air conditioners, bicycles, automobile components, shoes, typewriters, washing machines, and other products were located within the city. Beginning with construction of the Erie Canal, and supported by this broad industrial base, Syracuse developed a diverse ethnic and cultural population that remains today, and because it is a microcosm of the USA, the city is a popular location for market research surveys. According to the Census Bureau estimates for 2004, the Syracuse–Auburn combined statistical area (CSA) has a population of about 736,000, and the City of Syracuse alone has a population of just over 143,000 persons and just fewer than 60,000 residential units.

Fieldwork for the Syracuse Urban Metal Mapping and Exposure Research (SUMMER) project was carried out from mid-May to mid-August during the years 2003 and 2004. The sampling strategy approximated a tessellation (uniform geometric grid) stratified random (TSR) design. Each 1-min latitude-by-1-min longitude grid section was subdivided into six equal working grid elements (WGE). Field teams were asked to find three residential locations within each WGE from which, with the occupants' permission (in compliance with an Institutional Review Board-approved protocol), floor wipe samples could be obtained. Sampling followed the U.S. Environmental Protection Agency (EPA) wipe test protocols (USEPA 1995a) with two exceptions: (1) for several weeks in 2003, Whatman No. 1 filter paper was used instead of ASTM E1792 certified media, and (2) dried, pre-weighed wipe media were employed, necessitating wetting with a deionized water mist prior to use. During the 2004 field season, initial efforts were directed toward completion of a citywide coverage; as time allowed, more intensive spatial sampling was carried out in two separate sections of the city. Figure 1 shows the geographic distribution of sampling locations for the combined 2-year fieldwork program; its coarse resolution preserves confidentiality.

Dust loading measurements

The mass of dust per square foot of smooth floor area was measured gravimetrically. Over the course of the

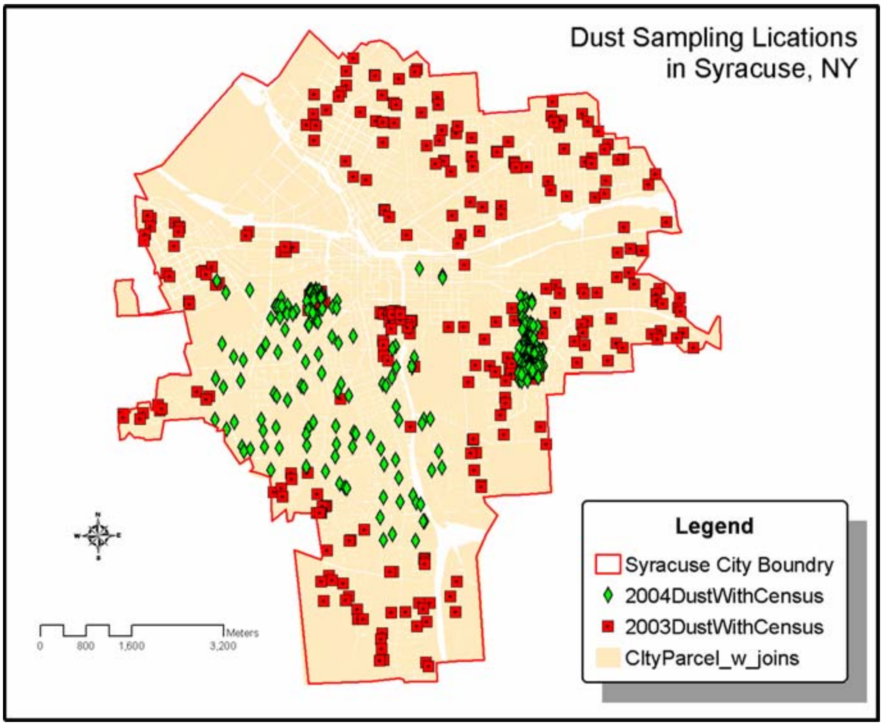

Fig. 1 Geographic distribution of floor dust sampling locations for the 2003–2004 Syracuse Urban Metal Mapping and Exposure Research (SUMMER) project

study, three different dry, pre-weighed wipe media were employed, but all used a similar collection procedure. Whatman Filters (cellulose) have low chemical blank values and have been used in previous studies (USEPA 1995b), but they performed poorly under field conditions and their use was discontinued. They were used directly from their packing containers. "Ghost Wipes" (cross-linked polyvinyl alcohol) and "Lead Wipes" (rayon; both meeting ASTM E1792 criteria for clearance tests) were removed from their foil packages, spread out between two layers of Kimwipe tissue, and allowed to air dry in the laboratory for at least 5 days prior to use. Dry wipes were placed in individually numbered 50-ml plastic centrifuge tubes and the initial weights recorded to the nearest 0.1 mg using a Denver Instrument M-220 balance. In the field, the wipes were misted with deionized water prior to use, samples obtained using USEPA procedures (USEPA 1995a), and the tubes re-capped and brought back to our laboratory for processing. Wipes were removed to individually numbered glass beakers, dried in an oven at 65–70°C overnight, and then returned to their centrifuge tubes. After oven drying, the wipe samples were allowed to equilibrate with ambient laboratory relative humidity for at least 4 days prior to their re-weighing for mass gain determinations. At both the initial and final weighing, wet and dry bulb temperatures were recorded to the nearest 0.03°C.

All three wipe media were sensitive to changes in ambient air moisture; over the range of conditions experienced in our laboratory, weight changes of up to 35 mg were experienced for wipes due to extreme changes in relative humidity. Weight correction functions were determined for each type of wipe material by incubating the materials in a range of constant humidity environments using their folded configuration inside open centrifuge tubes. Weight change functions were derived from empirical fits of mean ($n = 5$) weight gain or loss in regressions against the vapor pressure of water calculated from wet and dry bulb temperature measurements. As shown in Fig. 2, the Lead Wipes display the strongest influence from changes in laboratory air moisture content, while the Ghost Wipes display the weakest dependence—about half that of the Whatman Filters and the Lead Wipes. In replicate experiments, weight loses due to the oven drying process were observed for both the Lead Wipe (-2.0 mg, $n = 10$) and the Ghost Wipe (-3.0 mg, $n = 21$) media. This may

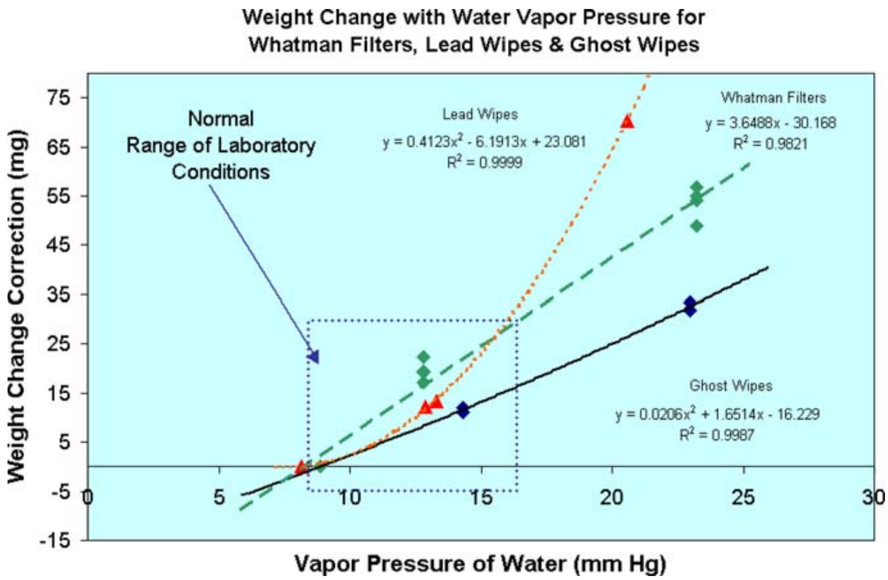

Fig. 2 Empirical weight change functions used to correct wipe sample gravimetric dust loading determinations for the effects of relative humidity changes in laboratory air

have been due to the loss of volatile substances contained in the wet wipe preparations. Blank corrections were applied to the field measurements, adding back those mean mass values to the respective media. The Whatman Filters exhibited no mass loss from the drying process. However, field blanks from the initial weeks of the 2003 sampling year showed an average weight gain of 5.0 mg for the filter papers (Johnson et al. 2005). This is now understood to have been caused by the lack of laboratory atmosphere equilibration of the Whatman Filters prior to their initial weighing before field use; the filters were packaged at a lower relative humidity than that of our laboratory. Therefore, a (negative) 5.0 mg mass correction was applied to all field results that used Whatman Filters.

Measured dust mass loading was limited by the combined uncertainties associated with weight determinations and the corrections for variations in atmospheric moisture content. A mass detection limit was estimated for the different wipe media as threefold the variance of corrected sample weights of specimens equilibrated at different relative humidities. For the Whatman Filters ($n = 22$), the detection limit was 1.3 mg, for the Lead Wipes ($n = 32$) it was 1.8 mg, and for the Ghost Wipe media ($n = 20$) it was 2.1 mg. Humidity equilibration time was followed for the various media by tracking their weight gain after removal from the drying oven; 72 h was sufficient for corrected sample weight differences to be below these detection limits. For the Lead Wipes, a first-order kinetic response with respect to the vapor pressure of water in air was observed with a half-life of about 8 h.

Comparison of wipe media

The three types of media employed in this study show differing abilities, under field conditions, for the recovery of dust from smooth floor surfaces. In order to study possible geographic patterns of floor dust mass distribution, the gravimetric results from different media were normalized to the measurements obtained from the dried Ghost Wipe media. This was accomplished through a side-by-side comparison of dust loading results as well as via determination of the dust collection efficiency of the various media.

Ten comparisons were made between Whatman Filter paper and dried Ghost Wipe media; five of these were field samplings in residential locations, and five were carried out in "laboratory" buildings on the State University of New York (SUNY)/Environmental Science and Forestry (ESF) campus. For eight of the comparisons, triplicate dust loading measurements were made using each type of wipe within a 3-by-4-m kitchen-sized space; two comparisons were made using five replicates for each medium. As noted by Johnson et al. (2005), floor dust loading is log-normally distributed; consequently, the geometric mean (GM) gravimetric dust mass was determined for each medium type in the various collection locations. The ratio of GM dust mass on Ghost Wipes to that on Whatman Filters was computed to be 1.24. A measure of the dust collection efficiency for each type of wipe was obtained from the fraction of dust mass collected by the first wipe with respect to the total dust mass obtained by three successive wipes of the same floor area. Collection efficiency was determined to be 81% (±2.8%, 1 SD, $n = 8$) for the Ghost Wipes and 67% (±9.2%, 1 SD, $n = 8$) for the Whatman Filters. Within experimental uncertainty, differences in the side-by-side comparison of Whatman Filters with Ghost Wipes can be explained by their respective dust collection efficiencies.

During the 2004 field season, 228 residential locations were sampled for floor dust loading using dried, pre-weighed Lead Wipe media. Preliminary experiments indicated that their collection efficiency was substantially less than that of the Ghost Wipes, so two successive wipes were employed for each location of the template on a kitchen floor surface. A side-by-side comparison of the single Ghost Wipe and double Lead Wipe sampling procedure was conducted at ten different locations; six of these are residential properties, and four are SUNY/ESF campus loading dock and access hallway locations. Figure 3 shows the results of this comparison, indicating that, on average, the use of two Lead Wipes collects the same dust mass as one Ghost Wipe. To verify this result, from the perspective of collection efficiency, the mass fraction collected on the first Lead Wipe in a two-wipe series was computed for 287 field locations (144 residences). The first wipe mean and median mass fractions collected were 0.656 (±0.121, 1 SD) and 0.636, respectively. Using the median value, assuming the same fraction of mass removed by each successive wipe, and defining total dust mass removed as that collected by three sequential wipes, we estimated the combined removal efficiency of the two Lead Wipes to be 82.8%, which compares favorably with the aforementioned 81% efficiency for the Ghost Wipes. Twenty-eight houses were sampled with a single application of the Lead Wipe media in each template; dust mass was normalized to the two-wipe efficiency.

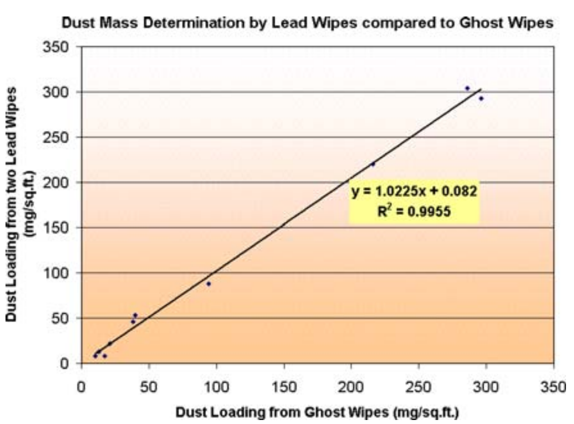

Fig. 3 Comparison of gravimetric floor dust loadings determined from side-by-side comparisons of Ghost Wipes and two successive Lead Wipes

Results and discussion

A total of 1064 smooth floor gravimetric dust mass loading collections from 488 residential locations in Syracuse, New York, are available from the 2-year study project. After blank corrections, the application of normalization factors and a logarithmic (Log 10) transformation, the statistical distribution is the one appearing in Fig. 4—a normal quantile plot of the results. The GM value for floor dust loading is 0.325 g m^{-2} (30.2 mg foot^{-2}), with a geometric standard deviation (GSD) of 2.65, giving a range of 0.123–0.866 g m^{-2} (11.4–80.5 mg ft^{-2}) at 1 SD. The minimum observed loading is below detection (about 0.04 g m^{-2} or 4 mg foot^{-2}), and the maximum in our sample is 13.860 g m^{-2} (1288 mg foot^{-2}). If the results are summarized by house, after computation of the GM dust loading for each residence, nearly identical values are obtained—a GM loading of 0.311 g m^{-2} (28.9 mg foot^{-2}) with a GSD of 2.73 gives a range of 0.114–0.851 g m^{-2} (10.6–79.1 mg foot^{-2}) at 1 SD. This data summary by house is used in all subsequent analysis; 95% of the observations fell in the range 0.043–2.313 g m^{-2} (4–216 mg foot^{-2}).

Duplicate (or more) measurements of dust loading were carried out at 470 residences (96.3%), allowing an estimate of intra-house variability in loading to be made. The median value of the GSD so obtained is 1.265, as compared with the value of 2.737 computed for the population of individual house results. On average, the between-house variability is more than twofold the within-house variability; 94% of the intra-house GSD estimates are less than the inter-house value.

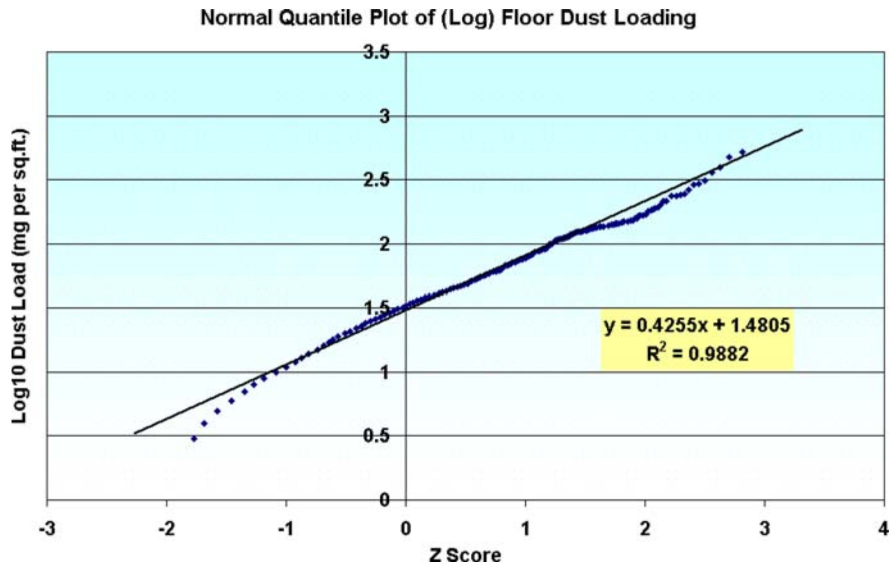

Fig. 4 Normal quantile plot of the log-transformed floor dust loading determinations of the Syracuse SUMMER study

Floor dust loading is a dynamic parameter, representing, at any point in time, the net positive difference between deposition (outdoor soil track-in as well as internal fluxes of skin flakes, textile fibers, toast crumbs, etc.) and removal processes, each of which may have continuous and stochastic components. Continuous track-on/track-off processes would tend toward homogeneous spatial loading within a house, while recent, event-based phenomena could lead to the heterogeneous distribution of floor dust observed in many houses. Differences in dust loading between houses are, perhaps, greater than intra-house variability for two reasons. First, continuous dust transport processes are interrupted periodically by stochastic cleaning events. Different households are likely to exhibit asynchronous cleaning cycles of variable magnitude and to be at different positions within those cycles when the dust samples were collected. Second, the magnitude of the dust transport and deposition fluxes may be different between households due to variation in factors such as number of persons living in a house, their lifestyle, presence or absence of pets, variation in ground cover and landscaping on the property, and condition of the housing unit.

Without detailed knowledge of the cleaning regimes employed at each residential location, variation due to position within a cleaning cycle is difficult to quantify. However, a limited time trend analysis was carried out on the floor wipe data by computing the GM (and its SD) dust loading by day of the week (DotW) and year of collection. The results, shown in Table 1, have been limited to the 95% of observations contained within the ±2 SD shown in Fig. 4—that is, for dust mass loadings between 0.043 and 2.330 g m^{-2} (4 and 216 mg foot^{-2}). The daily summaries are separated for the 2 years of sample collection because of the differences in spatial coverage, as shown in Fig. 1. In both years, the lowest GM dust loadings were from samples collected on Fridays, and the highest from samples collected on Thursdays, suggesting that there may be some similarity in the timing of floor cleaning activities across the region sampled. For the 2003 data set, the peak Thursday loading is significantly different ($\alpha = 0.05$) from those computed for the other days of the week; for the 2004 field year, the minimum average loading from the Friday collections is significantly different ($\alpha = 0.05$) from those of the other days of the week.

When the results are compiled by house from the complete 2-year data set, a qualitatively similar time trend can be observed (Table 2). On average, the highest dust loadings were measured from the Thursday collections, and the lowest loadings were from the Friday samples. Across the geographic area studied, this could be explained by Friday morning house cleaning prior to the arrival of the sampling teams. The magnitude of the possible "cleaning effect" was estimated from a first-order time

Table 1 Geometric mean (GM) value of floor dust loading by day of the week

Year	Day	GM of dust load (mg foot^{-2})	Mean of Log 10 dust load	Standard deviation of Log 10 dust load	*n*
From the population of wipe samples with outliers removed					
2003	Monday	24.5	1.3900	0.3712	93
2003	Tuesday	24.9	1.3966	0.3611	116
2003	Wednesday	22.5	1.3520	0.3699	147
2003	Thursday	34.4	1.5370	0.3625	97
2003	Friday	20.7	1.3167	0.3451	68
2004	Monday	40.4	1.6059	0.2839	83
2004	Tuesday	44.6	1.6494	0.2947	88
2004	Wednesday	46.2	1.6642	0.3761	144
2004	Thursday	46.2	1.6647	0.3120	75
2004	Friday	31.4	1.4968	0.3453	93
From the total population of geometric mean dust loadings by house					
Both	Monday	28.0	1.4471	0.3736	85
Both	Tuesday	31.9	1.5038	0.4099	100
Both	Wednesday	26.3	1.4210	0.5247	139
Both	Thursday	35.9	1.5557	0.3935	85
Both	Friday	24.4	1.3878	0.3959	78
From the total population of dust loadings by house with specific days excluded					
Both	Not Monday	29.1	1.4641	0.4498	403
Both	Not Tuesday	28.2	1.4502	0.4438	388
Both	Not Wednesday	30.0	1.4772	0.3967	349
Both	Not Thursday	27.6	1.4412	0.4437	403
Both	Not Friday	29.9	1.4751	0.4436	410

synchronizing model for the log-transform of the measured dust loading. We computed the ratio of the daily GM loading (Table 1, middle) to that of the other days of the week (Table 1, bottom), applying this "DotW correction" factor to the log-transformed data prior to their summarization by aggregation across spatial elements.

The second factor, spatial variation in floor dust loading, was examined with geographically averaged data summaries. The individual house GM dust loadings were aggregated by census tract and mapped as mean dust loading, using as points the census tract centroids. These results, and those corrected for the "cleaning effect," are presented in Table 2. An inverse distance-weighted interpolation [ArcMap ver. 9.1; Environmental Systems Research Institute (ESRI), Redlands, CA] was employed to make the map, shown in Fig. 5, from the model data in Table 2 corrected for cleaning effect bias. Census tract points were only included if at least four houses (nominally eight dust wipes) had been sampled. Strong spatial patterns of floor dust loading in Syracuse are evident in this rendering, spanning more than an order of magnitude. The highest values were observed in the near-west and southwest parts of the city; minimum values were found toward the borders away from the city center. As indicated in Table 2, little difference in this general pattern is observed if the census tract summaries are mapped without any correction for DotW sampling.

If the floor dust loading mapped across a large number of households is independent of the time when samples are taken, then observed spatial variations may be a reflection of differences between the deposition and removal fluxes for dust. Such influences might be exerted differently in residences with differing incomes and lifestyles, as mentioned above. Thus, regional differences in a dust loading steady state may be observed for a time scale longer than the "cleaning cycle" as a result of different

Table 2 Geometric mean floor dust loading (mg foot^{-2}) and geometric standard deviations summarized by the Syracuse Census Tract; "model" results reflect attempts to remove bias from collections on different days of the week

CT	Houses	GM load	GSD load	GM model	GSD model	Difference
2	10	37.19	2.61	39.29	2.82	2.10
3	3	11.27	3.18	11.28	3.17	0.02
4	8	11.48	2.85	11.62	2.80	0.14
6	3	12.29	2.03	11.82	2.27	−0.47
7	3	26.50	5.19	32.54	5.75	6.04
8	2	18.03	1.24	18.67	1.24	0.65
9	12	22.52	1.83	22.06	1.93	−0.45
10	8	27.08	2.07	21.87	1.94	−5.20
14	2	40.30	4.97	46.63	5.30	6.33
16	1	46.37		53.95		7.59
17.01	4	30.30	2.00	31.59	2.02	1.28
17.02	5	16.69	1.94	19.44	2.07	2.74
18	4	18.45	1.07	18.18	1.12	−0.27
19	12	17.57	2.09	17.57	2.11	0.00
20	10	13.78	2.83	14.28	2.93	0.49
21	2	21.27	8.48	17.00	7.25	−4.26
22	5	9.33	2.47	9.63	2.52	0.30
23	3	49.20	1.91	36.99	1.82	−12.21
24	1	80.70		85.11		4.41
27	5	29.46	1.41	29.03	1.53	−0.43
28	7	50.26	1.42	38.45	1.35	−11.81
29	2	44.79	1.11	41.83	1.22	−2.96
30	40	96.36	2.05	97.97	2.06	1.61
34	3	48.66	1.49	60.03	1.45	11.37
35	10	44.82	2.57	38.31	2.83	−6.51
36.01	2	7.75	2.17	7.20	2.11	−0.55
36.02	1	2.00		2.09		0.09
38	3	49.62	1.63	39.36	1.69	−10.27
39	8	52.43	1.58	53.08	1.59	0.64
40	16	57.31	1.84	65.30	1.87	7.99
42	20	53.38	3.11	52.23	2.94	−1.16
43	15	39.83	2.00	39.81	1.94	−0.02
44	4	28.02	2.73	23.56	2.26	−4.47
45	84	31.54	1.87	33.50	1.87	1.96
46	27	10.25	3.45	10.36	3.55	0.11
48	11	19.83	2.48	18.89	2.18	−0.94
49	8	26.02	1.78	24.28	1.83	−1.74
50	8	32.73	1.77	33.30	1.72	0.56
51	7	30.36	1.91	26.63	1.70	−3.73
52	9	45.91	1.61	46.68	1.56	0.77
53	6	35.82	1.48	31.83	1.72	−3.98
54	5	49.34	2.62	44.90	2.39	−4.44
55	5	36.84	1.76	40.97	1.67	4.13
56.01	11	13.69	2.28	13.88	2.26	0.19
56.02	1	12.25		13.52		1.27
57	15	19.06	2.25	18.72	2.28	−0.33
58	6	42.00	1.48	43.99	1.42	2.00
59	4	51.29	1.90	62.34	1.87	11.06
60	14	13.96	2.53	14.67	2.43	0.71
61.01	16	24.13	3.02	25.55	3.11	1.42
61.02	3	29.89	1.06	23.31	1.05	−6.58
61.03	14	10.82	3.40	10.64	3.32	−0.18

GSD, Geometric standard deviation; GM, geometric mean; CT, (Syracuse) Census Tract

population demographics. To examine this possibility, we carried out a multiple linear regression analysis, with census tract (DotW-corrected) GM dust loadings as the dependent variable, using various socio-economic/demographic covariates from the 2000 U.S. Census as independent regressors. Our initial analysis has not been exhaustive; it was designed to explore the qualitative nature of demographic factors that might influence interior floor dust mass.

A variety of models were examined using SAS (Proc Stepwise; SAS Institute, Cary, NC), and correlation coefficients were highly dependent upon the minimum number of observations for census tracts to be included in a regression model. When the minimum number of houses sampled per census tract is restricted to seven, the results are as indicated in Fig. 6, along with the regression equation for predicting the (DotW-corrected) GM floor dust loading by census tract. The model incorporates results from 400 houses in 25 census tracts across the City of Syracuse. The variables "fsize" (family size) and "den" (population density, persons per square mile) were extracted directly from the 2000 Census publications. The variable "frent", the fraction of renter-occupied housing units, was calculated from the population of residential units in each tract and their status as either renter or owner occupied, or vacant. "vhdol" is an aggregate (real estate) "desirable area" variable that is computed as the median household

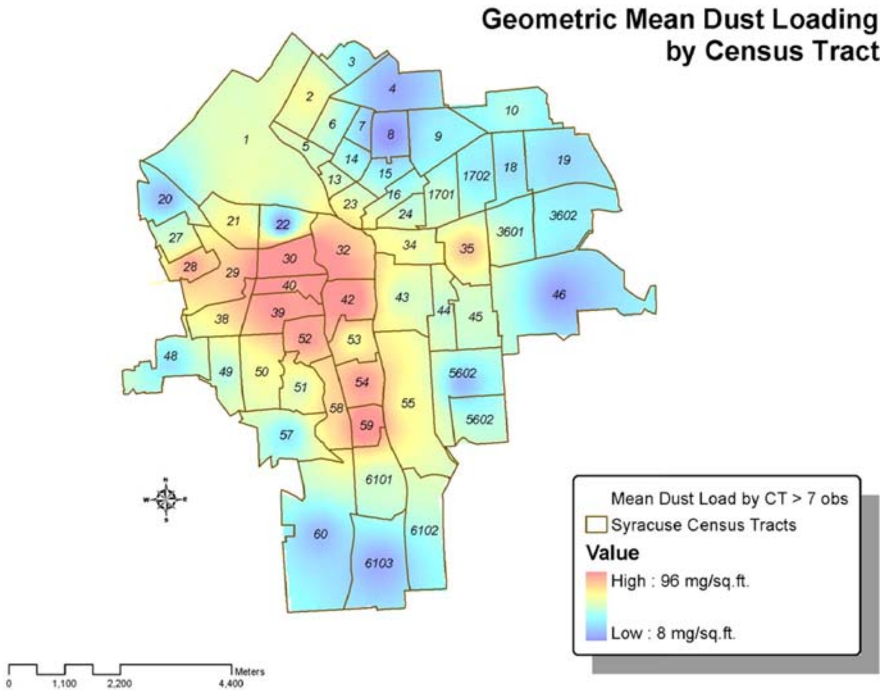

Fig. 5 Spatial patterns of floor dust loading aggregated by census tract (*CT*) and mapped by an inverse distance weighted algorithm

income (in thousands of U.S. dollars) multiplied by the fraction of vacant housing per tract.

Our results show the strongest relationship between increased floor dust loading and higher fractions of renter-occupied housing (partial $r^2 = 0.477$), with family size making the second largest contribution (partial $r^2 = 0.243$). The positive correlation with rental properties and the negative correlation with household income (partial $r^2 = 0.107$ for "vhdol") might be taken as objective support for a stereotypical view based on anecdotal accounts. The second factor, while perhaps intuitive, is supported by the experimental observations of Hunt et al. (2006) who showed that external soil transport to the indoor environment is substantially facilitated by multiple track-in events. Population density shows a small negative correlation with GM spatial patterns of dust loading (partial $r^2 = 0.020$); it may be explained by the presence of apartment complexes for which track-in is reduced by deposition to floors outside an apartment, or to the smaller family size in residences of predominantly older persons. The geographic distribution of high floor dust loadings is strikingly similar to the pattern of elevated blood lead values in Syracuse children (Griffith et al. 1998; Johnson and Bretsch 2002), and some researchers have found strong socio-economic/demographic correlates for elevated blood lead values (Johnson et al. 1996; Sargent et al. 1995). The strong association of high floor dust loading values with some of these same variables helps to suggest a mechanistic connection between poverty and poor living conditions and the potential for exposure to contaminants in urban soils and dusts.

Conclusion

1. We found the measurement of residential floor dust loading using pre-weighed wipe media to be a practical monitoring methodology. The two wipes certified (ASTM E1792) for lead clearance test use, "Ghost Wipe" and "Lead Wipe," performed well in field sampling after they had been dried, equilibrated with ambient laboratory atmospheres, and weighed prior to use. Recovery efficiency, as assessed from multiple sequential wiping, was found to be >81% for the Ghost Wipe media, but only about 63% for the Lead Wipe material. However, in side-by-side tests, equivalent dust loadings were determined when one Ghost Wipe was compared to two sequential

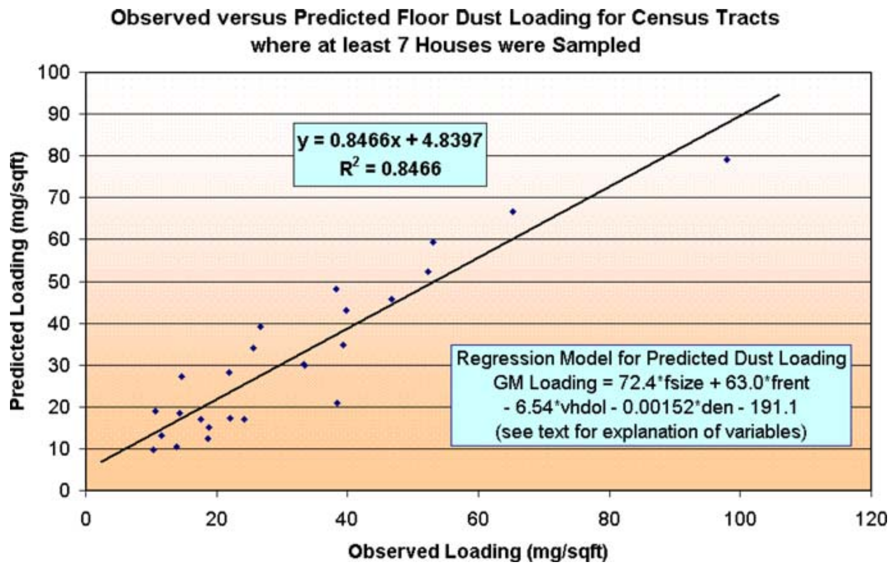

Fig. 6 Observed versus predicted floor dust loading by census tract

Lead Wipe applications from the same floor template. The Whatman Filter media recovered only about 80% of the mass obtained by a single Ghost Wipe, or a double Lead Wipe sampling. The filter papers are not strong enough to resist shredding under field conditions, leading to an underrepresentation of dust mass.

2. All three wipe media were sensitive to mass uncertainty in weighing due to changes in ambient laboratory air relative humidity. However, such weight changes can be corrected, after calibration, by careful monitoring of wet and dry bulb temperatures at the time of weighing. After oven drying, equilibration with ambient atmospheric conditions requires about 72 h. Provided no dramatic laboratory humidity/temperature changes had occurred immediately prior to the weighing operations, mass detection limits were found to be <2 mg. Our results suggest that the limit of quantitation (LOQ) for the methodology is on the order of 5 mg.
3. House dust loading was observed to have a log-normal distribution across the study area, with a GM value of 0.311 g m^{-2} (29 mg dust per square foot); the GSD of 2.73 translates into a range of 0.043–2.330 g m^{-2} (4–216 mg $foot^{-2}$) for inclusion of 95% of the observations. Based on duplicate collections within houses, the estimated intra-house variability was found to be twofold lower (GSD of approx. 1.265) than the inter-house variability.
4. Findings indicate a slight bias in results associated with the DotW for which samples had been collected. When viewed without geographic stratification, the lowest dust loading results were obtained from residences visited on Fridays, whereas the highest results were observed for Thursday samplings. This "cleaning effect" phenomenon associated with our wipe sampling methodology needs further investigation and should be a consideration for future environmental dust monitoring programs.
5. When data are aggregated at the census tract level, significant spatial patterns are observed. The average size of the Syracuse Census Tracts is about 1.2 km^2 (0.37 $mile^2$) when viewed at that scale of data summary, and GM floor dust loading ranges from roughly 0.100 to 1.000 g m^{-2} (10–100 mg $foot^{-2}$). Aggregated floor dust loadings are strongly correlated with socio-economic/demographic variables tabulated for the Syracuse Census Tracts. The most important positively correlated covariates in this empirical relationship are the fraction of renter-occupied housing in a census tract and the average family size; a negative influence is observed for household income.
6. The strong spatial patterns that exist in floor dust loading, spanning an order of magnitude in value and observed at a geographic scale of 1–2 km, closely relate to socio-economic/demographic aspects of a residential population and are

important factors to consider in environmental monitoring programs for household dust or in the development of urban soil contaminant exposure models.

Acknowledgments This work was supported by a grant from the National Science Foundation: award BCS-0221949. The authors thank Mark Storrings for his assistance with the GIS programs.

References

Butte, W., & Heinzow, B. (2002). Pollutants in house dust as indicators of indoor contamination. *Reviews of Environmental Contamination and Toxicology, 175*, 1–46.

Griffith, D. A., Doyle, P. G., Wheeler, D. C., & Johnson, D. L. (1998). A Tale of two swaths: urban childhood blood-lead levels across Syracuse, New York. *Annals of the Association of American Geographers, 88*(4), 640–665.

Hunt, A., Johnson, D. L., & Griffith, D. A. (2006). Mass transfer of soil indoors by track-in on footwear. *Science of the Total Environment, 370*(2–3), 360–371.

Johnson, D. L., & Bretsch, J. K. (2002). Soil lead and children's blood lead levels in Syracuse, New York, USA. *Environmental Geochemistry and Health, 24*(4), 375–385.

Johnson, D. L., Hager, J., Hunt, A., Griffith, D. A., Blount, S., Ellsworth, S., et al. (2005). Initial results for urban metal distributions in house dusts of Syracuse, NY, USA. *Science in China, Series C, 48*(Suppl 1), 92–99.

Johnson, D. L., McDade, K., & Griffith, D. (1996). Seasonal variation in pediatric blood levels in Syracuse, NY, USA. *Environmental Geochemistry and Health, 18*(2), 81–88.

Kildeso, J., Vallarino, J., Spengler, J. D., Brightman, H. S., & Schneider, T. (1999). Dust build-up on surfaces in the indoor environment. *Atmospheric Environment, 33*(5), 699–707.

Klepeis, N. E., Nelson, W. C., Ott, W. R., Robinson, J. P., Tsang, A. M., Switzer, P., et al. (2001). The National Human Activity Pattern Survey (NHAPS): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Analysis and Environmental Epidemiology, 11*(3), 231–252.

Lambert, T. W., & Lane, S. (2004). Lead, arsenic and polycyclic aromatic hydrocarbons in soil and house dust in the communities surrounding the Sydney, Nova Scotia, tar ponds. *Environmental Health Perspectives, 112*(1), 35–41.

Lanphear, B. P., Matte, T. D., Rogers, J., Clickner, R. P., Dietz, B., Bornshein, R. L., et al. (1998). The contribution of lead-contaminated house dust and residential soil to children's blood lead levels. *Environmental Research, 79*, 51–68.

Lemley, A. T., Hedge, A., Obendorf, S. K., Hong, S., Kim, J., Muss, T. M., et al. (2002). Selected pesticide residues in house dust from farmers' homes in Central New York State, USA. *Bulletin of Environmental Contamination and Toxicology, 69*(2), 155–163.

Lewis, R. G., Fortmann, R. C., & Camann, D. E. (1994). Evaluation of methods for monitoring the potential exposure of small children to pesticides in the residential environment. *Archives of Environmental Contamination and Toxicology, 26*(1), 37–46.

Lioy, P. J., Freeman, N. C. G., & Millette, J. R. (2002). Dust: a metric for use 3 in residential and building exposure assessment and source characterization. *Environmental Health Perspectives, 110*(10), 969–983.

Paustenbach, D. J., Finley, B. L., & Long, T. F. (1997). The critical role of house dust in understanding the hazards posed by contaminated soils. *International Journal of Toxicology, 16*(4–5), 339–362.

Pesonen-Leinonen, E., Tenitz, S., & Sjoberg, A. M. (2004). Surface dust contamination and perceived indoor environment in office buildings. *Indoor Air, 14*(5), 317–324.

Sargent, J. D., Brown, M. J., Freeman, J. L., Bailey, A., Goodman, D., & Freeman, D. H., Jr. (1995). Childhood lead poisoning in Massachusetts communities: its association with sociodemographic and housing characteristics. *American Journal of Public Health, 85*, 528–534.

Schneider, T., Kildeso, J., & Breum, N. O. (1999). A two-compartment model for determining the contribution of sources, surface deposition and resuspension to air and surface dust concentration levels in occupied rooms. *Building and Environment, 34*, 583–595.

Succop, P., Bornschein, R., Brown, K., & Tseng, C. (1998). An empirical comparison of lead exposure pathways. *Environmental Health Perspectives, 106*(Suppl 6), 1577–1583.

USEPA (1995a). Residential sampling for lead: protocols for dust and soil sampling. EPA Report 747-R-95-001. Environmental Protection Agency, Washington DC.

USEPA (1995b). Sampling house dusts for lead: basic concepts and literature review. EPA Report, 747-R-95-007. Environmental Protection Agency, Washington DC.